1.0

1.1

1.25   1.4   1.6

2.8   2.5

3.2   2.2

3.6

4.0   2.0

1.8

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Master's thesis,

THESIS

A STATISTICAL STUDY OF NOAP DATA.

by

Ali Ekmekci

Sep 78

Thesis Advisor: H. J. Larson

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A Statistical Study of Noap Data

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis examines spectrometric oil analysis data in an attempt to determine which of various sources can affect the spectrometer read-out.

The analysis of variance is used to a large extent in the study made of operational data gathered by the Naval Air Rework Facility, Pensacola, Florida. In order to satisfy the normality and independence assumptions of ANOVA, results obtained in a previous study on the same type of data have been used. Some transformations of the data have been made so that the third assumption, homogeneity of variance, can be more nearly satisfied.

TABLE OF CONTENTS

I. INTRODUCTION

For several years, the technique of using spectrometric analysis of oil samples as an aid in determining the condition of diesel engines has been employed successfully by major railroads and various other users of large diesel equipment.

In 1956, a trial program was begun at the Naval Air Rework Facility in Pensacola to determine if this method could also be used to monitor aircraft engines. Since that time, the program proved successful and evolved into the Naval Oil Analysis Program (NOAP).[1]

The oil reservoirs of reciprocating engines are sampled every 30 flight hours and the sample is then analyzed by a spectrometer using the rotating graphite electrode technique. The amount of each of 12 elements in the oil is recorded by the spectrometer in parts per million. These readings are used as an aid in determining what the operating condition of the engine might be. An assumption in making inferences about the condition of aircraft engines is that, if the engine is operating properly, the true amount of contamination in the oil should lie within normal limits. If excessive wear is present in an engine, it will presumably cause

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[1]In recent years, the oil analysis programs of the three services have been combined into the Joint Oil Analysis Program (JOAP).

an abnormal addition of metallic contaminants to the circulating oil. Therefore it is extremely important that the amount of contamination recorded at the laboratory accurately reflect the actual amount present in the engine.

In NOAP, there are a variety of potential sources which may cause erroneous spectrometer read-out. Some of these potential error sources are:

A. AMOUNT OF OIL USED IN ANALYSIS

Caps containing the sample oil for analysis are "filled", but no special effort is made to ensure the same amount of oil for each analysis.

B. ELECTRODE SOURCE

Two different electrode manufacturers have supplied electrodes to the NOAP in the past and both manufacturers' electrodes are available for use by NOAP laboratories. Therefore, any difference between two analyses, similar in all respects except source of manufacture of electrodes used in the analysis, can be attributed to the electrode source.

C. ELECTRODE TIP CONFIGURATION

Two different rod electrode tip configurations are being used in the oil analysis program. Any difference between two analyses in which everything for analysis is identical, except the electrode tip configuration, can be attributed to the different electrode type.

D. SAMPLE VISCOSITY

In NOAP, a high viscosity (heavy) oil base and a low viscosity (light) oil base are used both for spectrometer standardization and for wear metal analysis. Therefore any difference in spectrometer standardization produced by using standards of different viscosity may produce similar differences in wear metal sample analysis.

E. AMINE SULFONATE SAMPLE CONTENT

Small quantities of amine sulfonate are added into the calibration standards to retard the deterioration for their future use. Over time, the spectrometer readings for identically prepared oil samples, which differ in their amine sulfonate content, may not be equal.

F. SPECTROMETER TYPE

In NOAP, two different spectrometers, A/E35 U-3 and HB-2, are used for oil analysis. There are several differences in design between these two models. Therefore any difference in analysis of two sets of calibration standards, similar in all respects except that one set was analyzed with A/E35 U-3, the other with HB-2, may be attributed to the spectrometer type.

G. REUSING SAMPLES FOR ANALYSIS

Samples have sometimes been reused for analysis when the need was urgent and additional fresh samples were not available. Any difference between two identical analyses, except for the number of times that samples were used, can be attributed to reusing samples.

II. THE TSC REPORTS

The TSC technical reports, 1973 series [Ref. 1], consists
of 12 reports and each report examines the effect of a
single factor such as those described in I.A-I.G above. In
each report, usually more than one calibration standard with
"true" contaminant levels between 3 ppm and 300 ppm have been
used and the spectrometer analyses of these samples have
generally been repeated ten times for each level of the
factors considered. Sample means and estimates of standard
deviations were calculated for each element from the accumu-
lated data and they are available for the analysis presented
in this thesis. The original raw data collected were not
available for use.

If, for example, Y_i is the ith reading for iron in a
group of size N, then the sample mean, $\bar{Y}$, and the estimate
of the standard deviation, S, for iron are

$$\bar{Y} = (\sum_{i=1}^{N} Y_i) / N$$

and   (1)

$$S = [\sum_{i=1}^{N} (Y_i - \bar{Y})^2 / (N-1)]^{\frac{1}{2}}$$

In the NOAP report, the procedure in making decisions
was to compare the sample means and relative standard devia-
tions, element by element, for the same type calibration

standard.

Under this procedure, conclusions reached by NOAP associated with the factors considered in this report were as follows.

FACTOR	RESULT
Amount of oil	Different amounts of oil can cause a difference in read-out.
Electrode type	If the same configuration is used both for spectrometer standardization and for routine sample analysis, there will be no significant advantage of one configuration over the other.
Electrode source	Failure to restandardize the spectrometer when changing from one supplier's electrode to another's can produce very large errors in sample analysis.
Sample viscosity	Significant differences in A/E35 U-3 spectrometer read-out can be expected from oils having the same metal contents but different viscosities.
Amine sulfonate	0.48 percent amine sulfonate in the oil has no effect on the spectrometer read-out.
Spectrometer type	The read-out differences between the A/E35 U-3 and HB-2 spectrometers, although significant, are not large enough to warrant immediate replacement of the HB-2 instrument.
Reusing sample	Reusing samples has no effect on the spectrometer read-out.

III. <u>ANALYSIS PERFORMED</u>

In each NOAP report, the effect of a single factor (e.g. the amount of oil placed in the cap) is investigated at each of several different contaminant levels. The possibility then exists that the effect of the factor considered (say a two-thirds full cap versus a full cap) is not the same for all contaminant levels, i.e. that the factor and contaminant level interact.

In NOAP, the interaction effect was not explicitly considered. By using the summarized NOAP data, analyses of variance (ANOVA) were conducted to statistically test the effects of the factors and whether there exists any interaction between the calibration standard and the factor considered.

Since problems of ANOVA are actually problems of multiple regression in which the design matrix has a very special form, the NOAP data should satisfy the three assumptions of multiple regression problems which are normality, independence and homescedasticity of observations.

A test for normality couldn't be conducted because the original NOAP data were not available in unsummarized form. However, a previous study [Ref. 2] was done on spectrometer readouts of this type. It concluded that the readings appear to be consistent with samples from normal populations. Therefore it's assumed that the normality requirements are

met for the NOAP data. In the same study, significant corre-
lations between the element readings were found. For this
reason the elements are analyzed individually in this study,
to avoid the dependence between element readings. Since all
readings were carefully made, in the NOAP data under ideal
conditions, it's assumed the readings obtained are independent
(for the same element).

For each element, variances were increasing with the con-
centration level of the calibration standard. Since homesce-
dasticity means that all observations in the analysis have the
same variance, it was desirable to stabilize the variances.

It has been suggested by Baird Atomic, Inc., that the
variability in readings for a given element is dependent on
the true content of the element. Therefore the model (2)
was investigated and parameters k and m were determined to
produce the best transformation of S and $\bar{Y}$ through which a
line could be fitted with minimum error.

$$S^n = a + b \cdot \bar{Y}^k \qquad\qquad (2)$$

A. DETERMINING THE TRANSFORMATION

In order to decide what kind of transformation should be
applied, a scatter plot was used. Data included in report 3
whose subject is the effect of electrode source on the spec-
trometer read-out were chosen for the study with the scatter
plot.

In the scatter plot, the estimates of the standard devia-
tions, S, were plotted versus the associated sample means, $\bar{Y}$,

and the idea in determining the transformation was to reduce
the vertical distance among points since there was already
a rough linear structure among the points.

Some of the estimates of the standard deviations were be-
tween zero and one; the others were greater than one. It
was found that values for k and m greater than one did not
provide a very good fit to model (2). Thus, most of the in-
vestigation centered on values of k < 1. and m < 1.

First, the square root transformation was applied only
on S and the transformed S's were plotted versus the original
$\bar{Y}$'s. Since the linear structure was essentially destroyed
after the transformation, the same transformation was applied
to the sample means and the transformed estimate of the
standard deviations were plotted versus the transformed sample
means. After that operation the linear structure was again
more apparent. A demonstration of the procedure above is
given in the Computer Output Section.

In determining the goodness of fit of any transformation
(values for k and m in (2)), the multiple correlation coeffi-
cient R^2, was used as a measure of effectiveness.

$$R^2 = \frac{\sum_{i=1}^{N} [a + b \cdot \bar{Y}_i{}^k - \overline{S^m}]^2}{\sum_{i=1}^{N} (S_i{}^m - \overline{S^m})^2}$$

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where $\overline{S^m}$ is the average of the transformed estimate of the standard deviations and $a+b\bar{Y}_i^k$ is the value of the regression line through the transformed points at $\bar{Y}_i^k$ associated with S_i^m. a and b were estimated using least squares techniques [Ref. 4]. Having tried several transformations, the 5th root of the sample means and the standard deviations was accepted as an appropriate transformation and .2 was set as the value of both k and m because the values of R^2 did not change much for k and m smaller than .2.

The value of R^2 for different transformations is given element by element as follows.

TABLE I

VALUES OF R^2 FOR DIFFERENT TRANSFORMATIONS

Elements	Model			
	$\sqrt{S} = a+b\sqrt{\bar{Y}}$	$\sqrt[2,5]{S}=a+b\sqrt[2,5]{\bar{Y}}$	$\sqrt[5]{S}=a+b\sqrt[5]{\bar{Y}}$	$\sqrt[8]{S}=a+b\sqrt[8]{\bar{Y}}$
Fe	.722	.758	.827	0.852
Ag	.781	.80	.830	0.838
Al	.804	.794	.757	0.736
Cr	.626	.664	.742	0.769
Cu	.808	.824	.851	0.860
Mg	.828	.843	.871	0.880
Ni	.858	.834	.777	0.754
Pb	.802	.780	.715	0.684
Si	.873	.876	.881	0.883
Sn	.746	.706	.586	0.529
Ti	.787	.824	.887	0.900
Md	.875	.883	.889	0.888

The transformation using 5th roots was applied on reports included in this study to see if the same transformation might prove adequate for all reports.

The value of R^2 for each report is given under the subject names associated with the report as follows.

TABLE II

VALUES OF R^2 FOR EACH REPORT

MODEL	$^5\sqrt{S} = a + b \ ^5\sqrt{Y}$				
Report subject Element	Electrode Source	Sample Viscosity	Amine Sulfonate Sample Content	Spectrometer Type	Reusing Sample
Fe	0.9856	0.9450	0.9732	0.9486	--
Ag	0.9662	0.9423	0.9676	0.9067	--
Al	0.9456	0.8975	0.8802	0.7034	--
Cr	0.9946	0.9220	0.9421	0.5384	--
Cu	0.9982	0.9414	0.9779	0.8416	--
Mg	0.9540	0.9118	0.9443	0.9306	--
Ni	0.9594	0.9561	0.9642	0.9078	--
Pb	0.9640	0.9562	0.9220	--	--
Si	0.9735	0.9432	0.9715	0.8319	--
Sn	0.9098	0.9273	0.9439	0.5677	--
Ti	0.9945	0.8914	0.9629	0.8765	--
Md	0.9703	0.8785	0.8733	0.9123	--

One-way ANOVA was used for report 10 whose subject is reusing samples because just D12.100 calibration standard had been used by NOAP for analysis and transformation was not applied because homogeneity was satisfied for all elements except silver.

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B. APPLICATION OF THE TRANSFORMATION

Having decided upon the transformation, the model (2) was used to redetermine the estimated standard deviations. The method used was to adjust the transformed S's to some common value [Ref. 3]. The average of the transformed sample means was chosen as the common value because it is near the center of the range of the values of the transformed sample means.

The technique in adjusting the values of the transformed S's is to take account of differences among the associated values of the transformed sample means and can be described as follows

$$\text{ADJ. } S_i^m = S_i^m - b \cdot (\overline{Y}_i^k - \overline{\overline{Y^k}})$$
$$= \overline{S^m} + (S_i^m - \overline{S^m}) - b \cdot (\overline{Y}_i^k - \overline{\overline{Y^k}})$$
$$= \overline{S^m} + S_i^m - \hat{S}_i^m$$

where

$$\overline{S^m} = a + b \overline{\overline{Y^k}} \qquad \text{and} \qquad \hat{S}_i^m = a + b \cdot \overline{Y}_i^k$$

$\overline{\overline{Y^k}}$ is the average of the values of the transformed sample means.

Having obtained the adjusted values, the standard deviation estimates were determined as the 5th power of the corresponding ADJ. S_i^m.

Bartlett's test [Ref. 3] for homogeneity of variances was used with the new standard deviation estimates and test results were determined on the basis of the observed value of a χ^2 statistic; in other words these results are just significant at the level of significance equal to the tail area

which is the probability that a χ^2 random variable is equal or greater than the tabulated value of the statistic.

For some elements, test results led to rejection of homogeneity because, for higher contamination levels, there were some observed standard deviations which varied extremely from the fitted straight line. But the following analyses were run with these new values because most of the standard deviation estimates appeared homogeneous.

Test results with tail areas are given under the title of each report, except Report 1 and 10, as follows

TABLE III

RESULTS OF TEST FOR HOMOGENEITY OF VARIANCES

Element	Element Tip Configuration	Sample Viscosity
Fe	Accept for $\alpha \leq$ .90	Accept for $\alpha \leq$ .077
Ag	Accept for $\alpha \leq$ .50	Accept for $\alpha \leq$ .0091
Al	Accept for $\alpha \leq$ .50	Accept for $\alpha \leq$ .025
Cr	Accept for $\alpha \leq$ .95	Accept for $\alpha \leq$ .136
Cu	Accept for $\alpha \leq$ .99	Accept for $\alpha \leq$ .024
Mg	Accept for $\alpha \leq$ .30	Accept for $\alpha \leq$ .018
Ni	Accept for $\alpha \leq$ .70	Accept for $\alpha \leq$ .1966
Pb	Accept for $\alpha \leq$ .90	Accept for $\alpha \leq$ .95
Si	Accept for $\alpha \leq$ .38	Accept for $\alpha \leq$ .075
Sn	Accept for $\alpha \leq$ .83	Accept for $\alpha \leq$ .70
Ti	Accept for $\alpha \leq$ .90	Reject for all α
Mo	Accept for $\alpha \leq$ .70	Reject for all α

TABLE IV

RESULTS OF REST FOR HOMOGENEITY OF VARIANCES

Element	Amine sulfonate Sample content	Electrode Source
Fe	Accept for $\alpha \leq .70$	Accept for $\alpha \leq 0.05$
Ag	Accept for $\alpha \leq .1298$	Reject for all α
Al	Accept for $\alpha \leq .011$	Accept for $\alpha \leq 0.05$
Cr	Accept for $\alpha \leq .20$	Accept for $\alpha \leq 0.005$
Cu	Accept for $\alpha \leq .50$	Reject for all α
Mg	Accept for $\alpha \leq .1031$	Accept for $\alpha \leq 0.12$
Ni	Accept for $\alpha \leq .75$	Accept for $\alpha \leq 0.025$
Pb	Accept for $\alpha \leq .50$	Accept for $\alpha \leq 0.05$
Si	Accept for $\alpha \leq .60$	Accept for $\alpha \leq 0.025$
Sn	Accept for $\alpha \leq .75$	Accept for $\alpha \leq 0.009$
Ti	Accept for $\alpha \leq .45$	Accept for $\alpha \leq 0.025$
Mo	Reject for all α	Accept for $\alpha \leq .173$

TABLE V

RESULTS OF TEST FOR HOMOGENEITY OF VARIANCES

Element	Spectrometer Type
Fe	Accept for all $\alpha \leq .308$
Ag	Reject for all α
Al	Accept for all $\alpha \leq .0068$
Cr	Reject for all α
Cu	Reject for all α
Mg	Accept for all $\alpha \leq .022$
Ni	Accept for all $\alpha \leq .091$
Pb	-----
Si	Reject for all α
Sn	Reject for all α
Ti	Reject for all α
Mo	Accept for all $\alpha \leq .073$

C. RESULTS FROM ANOVA

In this study, the model used for ANOVA is

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + e_{ijk}$$

where

$$i = 1, ----, I$$

$$j = 1, ----, J$$

$$k = 1, ----, K$$

The parameter μ is called the overall mean and e_{ijk} is called the error in estimation. The parameters $\alpha_1, ---, \alpha_I$ are called the main effects of factor A, and the parameters $\beta_1, --- \beta_J$ are called the main effects of factor B. The parameters γ_{ij}, for $i=1,---,I$ and $J=1,---,J$ are called the interactions. I, J and K are the number of levels of the factor considered, the number of levels of contaminant and the number of replications for each combination of factors, respectively.

In finding the numerical values of the sum of squares in Table VI, the original sample means and the adjusted standard deviation estimates were used. The F statistic associated with the main effect of A is used to test the effect of the factor considered; the F statistic associated with the main effect of B is used to test the effect of level of contaminant and the F statistic associated with the interaction is used to test the interaction effect. ANOVA was used for each report, except Report 1 whose subject is the effect of the amount of oil used in analysis and

TABLE VI

ANOVA

Source of Variation	Degrees of Freedom	Sum of Squares	F Statistics
Overall mean	1	$I.J.K.\,(\bar{Y}...)^2$	
Main effects of A	$DF_A = I-1$	$SS_A = J.K \sum\limits_{i=1}^{I}(\bar{Y}_{i..} - \bar{Y}_{...})^2$	$\dfrac{SS_A/DF_A}{SS_R/DF_R}$
Main effects of B	$DF_B = J-1$	$SS_B = I.K \sum\limits_{j=1}^{J}(\bar{Y}_{.j.} - \bar{Y}_{...})^2$	$\dfrac{SS_B/DF_B}{SS_R/DF_R}$
Interaction	$DF_I = (I-1)(J-1)$	$SS_I = K \sum\limits_{i=1}^{I}\sum\limits_{j=1}^{J}(\bar{Y}_{ij.} - \bar{Y}_{i..} - \bar{Y}_{.j.} + \bar{Y}_{...})^2$	$\dfrac{SS_I/DF_I}{SS_R/DF_R}$
Residuals	$DF_R = I.J.(K-1)$	$SS_R = \sum\limits_{i=1}^{I}\sum\limits_{j=1}^{J}\sum\limits_{k=1}^{K}(Y_{ijk} - Y_{ij.})^2$	
Total	$I.J.K.$	$\sum\limits_{i=1}^{I}\sum\limits_{j=1}^{J}\sum\limits_{k=1}^{K}(Y_{ijk})^2$	

numerical results obtained from the analysis are given for
report 3 in the Computer Output Section.

D.   GRAPHICAL REPRESENTATION OF THE INTERACTION

Another way of explaining the interaction is to ask
whether the difference in response for various levels of the
factor considered is the same for all levels of contaminant.
If these differences are equal, there is no interaction.
Therefore the averages of the spectrometer read-out taken at
each level of contamination have been plotted versus the
true concentration of the contaminant levels and a line has
been estimated for each level of the factor considered.

Using a "t" test [Ref. 3], the slopes of the lines have
been compared to see whether the lines are parallel or not.
Results of the tests and the graphs show that the lines are
not parallel for most of the reports. The graphs for each
element were presented in the Computer Output Section for
report 2 whose subject is the effect of the electrode tip
configuration on the spectrometer read-out. Results of that
test for each report are given in the Computer Output Section.

IV. <u>CONCLUSION</u>

The investigation of the NOAP data led to the main con-
clusion that, generally there are interactions between the
level of contamination and most of the factors considered.
The results obtained for the effect of the factors were given
under the title of the associated reports considered in this
study. The results were obtained by ANOVA at the .05 level
of significance. For report one, amount of oil used in
analysis, a t test [Ref. 4] was conducted because just one
level of contamination had been used.

A. EFFECT OF THE AMOUNT OF OIL USED IN ANALYSIS

In comparing the full size sample with the 2/3 size
sample, it was determined that the means of the samples were
not equal for the elements, aluminum, chromium, copper,
nickel and tin. The observations using full size samples
had larger means. Since five of 12 elements have larger
means, the amount of oil used in the analysis can change the
spectrometer read-out.

B. EFFECT OF ELECTRODE TIP CONFIGURATION

For silver, there is no interaction effect between the
level of contamination and the electrode tip configuration,
but there is a statistically significant difference between
types of configuration.

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For other elements, the values of F statistics used to test interaction and the effect of the electrode type were larger than tabulated values at associated degree of freedoms. Therefore it may be said that there is interaction between the level of contamination and the electrode type, and that the effect of the electrode type is statistically significant.

C. EFFECT OF ELECTRODE SOURCE

1. On Taking Observations

There is a statistically significant interaction effect between the level of contamination and the electrode source. The effect of the electrode source is statistically significant. The observations taken by an electrode produced by manufacturer "A" are larger than the observations taken by an electrode produced by manufacturer "B" at each level of contamination for each element. Therefore it might be said that "A" electrodes produce a larger read-out.

2. On the Spectrometer Standardization

In order to see the effect of the electrode source in standardizing a spectrometer, readings, taken with "A" electrodes, on the spectrometer standardized with "A" electrodes were compared with readings, taken with "A" electrodes, on the same kind of spectrometer standardized with "B" electrodes. The same procedure was done with readings taken by "B" electrodes.

Results of analysis have shown that there is statistically significant interaction between the level of contamination

and the electrode source, and that the effect of electrode source is significant.

D. EFFECT OF SAMPLE VISCOSITY ON A/E35-U SPECTROMETER

There is a statistically significant interaction between the level of contamination and the sample viscosity.

For titanium, there is no effect of sample viscosity, but for the other elements the sample viscosity effect is statistically significant.

The observations taken with the heavy oil have a larger average read-out. Therefore it can be said that heavy oil produces higher read-out:

E. INITIAL EFFECT OF AMINE SULFONATE ON A/E35-U SPECTROMETER

There is a statistically significant interaction between the level of contamination and amine sulfonate in the oil.

For aluminum and tin, there is no effect of amine sulfonate, but for the other elements amine sulfonate effect is statistically significant.

F. EFFECT OF THE SPECTROMETER TYPE

There is a statistically significant interaction between the level of contamination and the spectrometer type.

The effects of the spectrometer types are not equal and the A/E35-U spectrometer produces larger read-out.

G. EFFECT OF REUSING SAMPLES

Reusing samples for analysis does not have any effect on the spectrometer read-out.

COMPUTER OUTPUT

In this section, scatter plots obtained by APL[1] are given. In each plot, components of Y vector are the transformed estimates of standard deviations and components of X vector are the transformed sample means as indicated above plots.

Following scatter plots, for report 3, original standard deviations and their adjusted values are given with the results from ANOVA for an element indicated on each page.

As a final part, results of "t" test examining slope of lines for interaction effect for each report and the graphs associated with the graphical representation of interaction for each element in report 2 are given.

---

[1]Arithmetic programming language.

A SQUARE ROOT OF STAND. DEV. VERSUS MEAN

Y←SIGMA1*.5

X←MEAN1

BSCAT X AND Y

```
RANGE OF X: 0    350
RANGE OF Y: 0    3
|
|
|                                    .
|
|
|
|          .
|
|      2
|   2    2
|            .
|.
|:
2
|-------------------------------------------
```
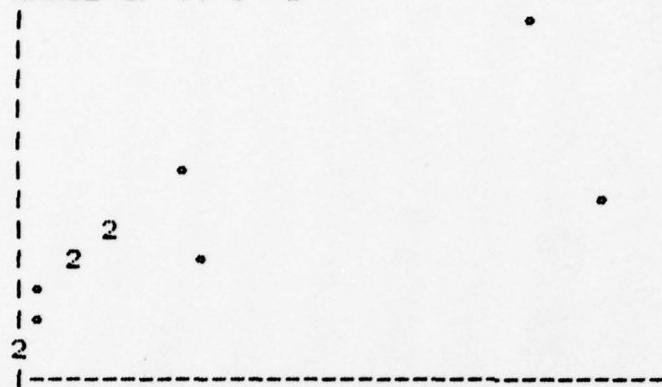
A SQUARE ROOT OF STAND. DEV. VERSUS SQUARE ROOT OF MEAN

Y←SIGMA1*.5

X←MEAN1*.5

BSCAT X AND Y

```
RANGE OF X: 0    20
RANGE OF Y: 0    3
|
|
|                          .
|
|
|              .
|                           .
|          ..
|        ..
|       ..        .
|    .
|    .
|   2
|-------------------------------------------
```
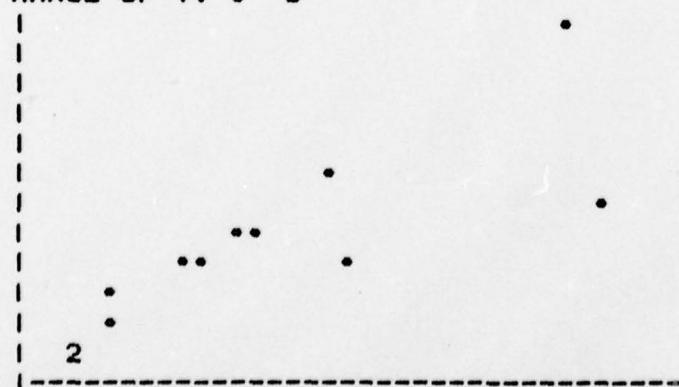
⌐ 2.5 TH. ROOT OF STAND. DEV. VERSUS 2.5 TH. ROOT OF MEAN.

Y←SIGMA1*.4

X←MEAN1*.4

BSCAT X AND Y

```
RANGE OF X: 0   12
RANGE OF Y: 0   2.5
|
|
|                                    .
|
|
|
|                      .
|
|             2
|                            .
|          ..
|      2
|     .
|     .
|
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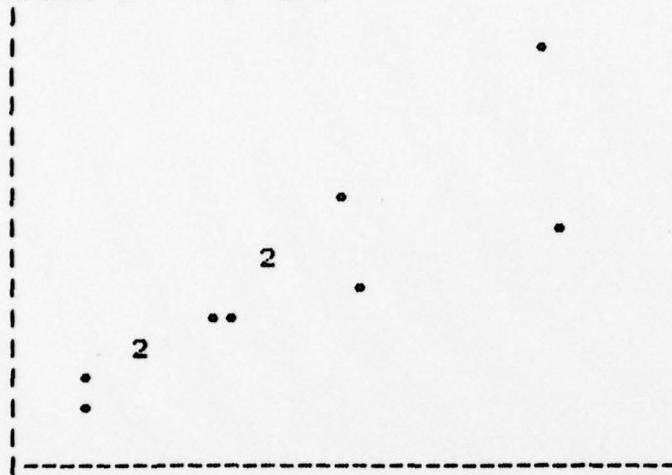
⌐ 5 TH. ROOT OF STAND. DEV. VERSUS 5 TH. ROOT OF MEAN.

Y←SIGMA1*.2

X←MEAN1*.2

BSCAT X AND Y

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RANGE OF X: 1   3.5
RANGE OF Y: 0.6  1.6
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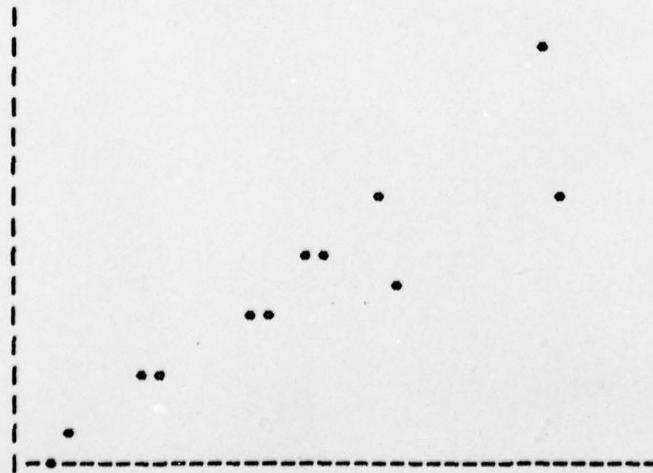
ELEMENT: IRON

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.13	0.8688
0.30	0.8579
0.8	0.9536
1.14	1.1638
0.9	0.3697*
2.3	0.3319*
0.1	0.7676
0.4	1.1183
0.8	1.0609
1.5	1.3458
2.8	1.5620
8.4	2.2710*

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	389198.875	
Effect of A	1	1534.162	1123.2006
Effect of B	5	634133.375	92853.062
Interaction	5	2459.881	360.188
Residuals	48	65.562	
Total	60	1027392.125	

ELEMENT: SILVER

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.06	1.1471
0.2	0.9620
0.3	0.3996
2.1	1.6053
0.9	0.2292
2.3	0.8093
0.13	1.8161
0.5	1.9918
0.7	1.0138
1.9	1.5698
3.3	1.3807
20.0	4.1744

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	328335.687	
Effect of A	1	1902.904	637.622
Effect of B	5	457607.562	30666.886
Interaction	5	4456.546	298.65
Residuals	48	143.25	
Total	60	792446.687	

ELEMENT: ALUMINUM

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.22	0.9811
0.3	0.6692
0.4	0.4738
1.5	1.3009
0.9	0.4641
3.6	0.9831
0.68	2.3071
0.5	1.0605
1.1	1.3343
1.7	1.5298
2.8	1.7548
5.6	1.8494

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	379180.75	
Effect of A	1	652.08	363.164
Effect of B	5	596132.187	66400.187
Interaction	5	1122.706	125.052
Residuals	48	86.187	
Total	60	977174.625	

ELEMENT: CHROMIUM

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.06	0.5928
0.2	0.6399
0.4	0.4957
1.3	1.0813
0.8	0.3313
1.6	0.1930
0.15	1.0513
0.5	1.3723
0.8	1.0030
1.1	0.9166
1.9	0.9507
11.9	3.3544

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	378036.75	–
Effect of A	1	190.093	118.212
Effect of B	5	582492.75	72446.00
Interaction	5	419.84	52.217
Residuals	48	77.18	
Total	60	961217.187	

ELEMENT: COPPER

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.08	1.1033
0.30	1.1409
0.4	0.5168
1.2	0.9436
1.1	0.3571
6.2	0.7923
0.11	1.3514
0.4	1.4445
0.5	0.6727
0.5	0.3850
2.3	0.9468
14.8	3.3501

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	331227.875	
Effect of A	1	918.83	523.1
Effect of B	5	453855.812	51676.98
Interaction	5	2959.404	336.96
Residuals	48	84.312	
Total	60	789046.50	

ELEMENT: MAGNESIUM

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.08	0.8589
0.3	0.9667
1.1	1.2763
2.2	1.7993
0.9	0.3098
4.9	0.7217
0.11	1.1387
0.6	1.7872
0.9	1.1984
1.2	1.0318
3.1	1.5686
10.1	2.3285

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	371541.062	-
Effect of A	1	1427.88	777.74
Effect of B	5	533159.937	58080.371
Interaction	5	2164.597	235.802
Residuals	48	88.125	
Total	60	908381.562	

ELEMENT: NICKEL

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.41	1.9951
0.2	0.6267
0.9	1.0959
1.4	1.2073
0.6	0.2425
7.7	1.8929
0.24	1.3290
0.9	2.1149
0.5	0.6450
1.2	1.0349
2.7	1.4542
7.3	1.9055

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	377211.062	
Effect of A	1	335.125	166.47
Effect of B	5	583194.125	57942.187
Interaction	5	1036.207	102.953
Residuals	48	96.62	
Total	60	961874.125	

ELEMENT: LEAD

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.91	2.6565
0.3	0.7197
1.4	1.5508
1.8	1.5723
1.1	0.5825
4.5	1.4885
0.46	1.5174
0.9	1.7905
0.5	0.5896
1.2	1.0501
2.7	1.0701
6.7	2.5978

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	372123.75	
Effect of A	1	581.59	221.338
Effect of B	5	540650.437	41151.585
Interaction	5	1408.646	107.219
Residuals	48	126.125	
Total	60	914890.500	

ELEMENT: SILICON

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.13	0.9720
0.3	0.8866
0.5	0.6177
1.3	1.0577
0.7	0.2630
4.6	0.8386
0.16	1.2039
0.3	0.9271
0.7	0.9292
1.7	1.4085
2.1	1.0570
7.6	1.8064*

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	383229.562	
Effect of A	1	582.839	508.659
Effect of B	5	591951.375	103322.375
Interaction	5	767.795	134.0153
Residuals	48	55	
Total	60	976586.875	

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ELEMENT: TIN

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.83	2.1958
0.10	0.2421
1.3	1.4575
1.3	1.1568
1.3	0.7718
3.7	1.2632
0.87	2.4744
1.0	1.8268
0.7	0.8297
0.9	0.8070
2.0	1.2886
6.9	2.8078

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	392993.437	
Effect of A	1	348.032	135.062
Effect of B	5	578058.812	44866.015
Interaction	5	495.559	38.46
Residuals	48	123.687	
Total	60	972019.937	

ELEMENT: TITANIUM

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.11	1.1743
0.20	0.7958
0.90	1.1091
1.7	1.3521
1.7	0.6119
4.1	0.4356
0.11	1.2743
0.4	1.4364
0.8	1.1371
1.1	0.9526
3.2	1.5210
14.6	3.2584

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	360652.687	
Effect of A	1	1436.672	704.574
Effect of B	5	536888.437	52660.320
Interaction	5	2163.481	212.203
Residuals	48	97.875	
Total	60	901239.125	

ELEMENT: MOLYBDENUM

ORIGINAL STANDARD DEVIATION ESTIMATES	ADJUSTED STANDARD DEVIATION ESTIMATES
0.58	3.0211
0.6	1.7265
1.6	1.8795
1.3	1.0060
2.3	0.9494
8.2	1.5590
0.25	1.8293
0.40	1.3108
1.3	1.7441
1.9	1.6793
3.0	1.5219
15.1	4.0814

ANOVA

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	F RATIO
Overall mean	1	408587.812	-
Effect of A	1	2021.89	486.013
Effect of B	5	601577.062	28920.875
Interaction	5	2688.41	129.245
Residuals	48	199.687	
Total	60	1015075.000	

RESULTS OF "t" TEST FOR TESTING SLOPE OF LINES

ELECTRODE SOURCE

ELEMENT	"t" STATISTICS	DF	RESULTS
Fe	26.851	116	Reject
Ag	0.000228	116	Accept
Al	34.438	116	Reject
Cr	38.236	116	Reject
Cu	14.528	116	Reject
Mg	16.736	116	Reject
Ni	14.541	116	Reject
Pb	20.565	116	Reject
Si	37.758	116	Reject
Sn	26.581	116	Reject
Ti	9.9422	116	Reject
Mo	4.2333	116	Reject

SAMPLE VISCOSITY

ELEMENT	"t" STATISTICS	DF	RESULTS
Fe	9.6622	108	Reject
Ag	21.641	108	Reject
Al	33.054	108	Reject
Cr	39.416	108	Reject
Cu	24.615	108	Reject
Mg	12.759	108	Reject
Ni	24.763	108	Reject
Pb	21.068	108	Reject
Si	18.286	108	Reject
Sn	29.192	108	Reject
Ti	-7.3733	108	Reject
Mo	-28.515	108	Reject

AMINE SULFONATE SAMPLE CONTENT

ELEMENT	"t" STATISTICS	DF	RESULTS
Fe	6.3138	108	Reject
Ag	11.928	108	Reject
Al	3.1288	108	Reject
Cr	10.074	108	Reject
Cu	12.654	108	Reject
Mg	2.9042	108	Reject
Ni	7.8093	108	Reject
Pb	3.7812	108	Reject
Si	9.3196	108	Reject
Sn	4.1561	108	Reject
Ti	7.7419	108	Reject
Mo	3.8196	108	Reject

SPECTROMETER TYPE

ELEMENT	"t" STATISTICS	DF	RESULTS
Fe	72.980	108	Reject
Ag	26.748	108	Reject
Al	27.914	108	Reject
Cr	34.062	108	Reject
Cu	21.223	108	Reject
Mg	23.754	108	Reject
Ni	14.511	108	Reject
Pb	-	108	Reject
Si	32.408	108	Reject
Sn	25.197	108	Reject
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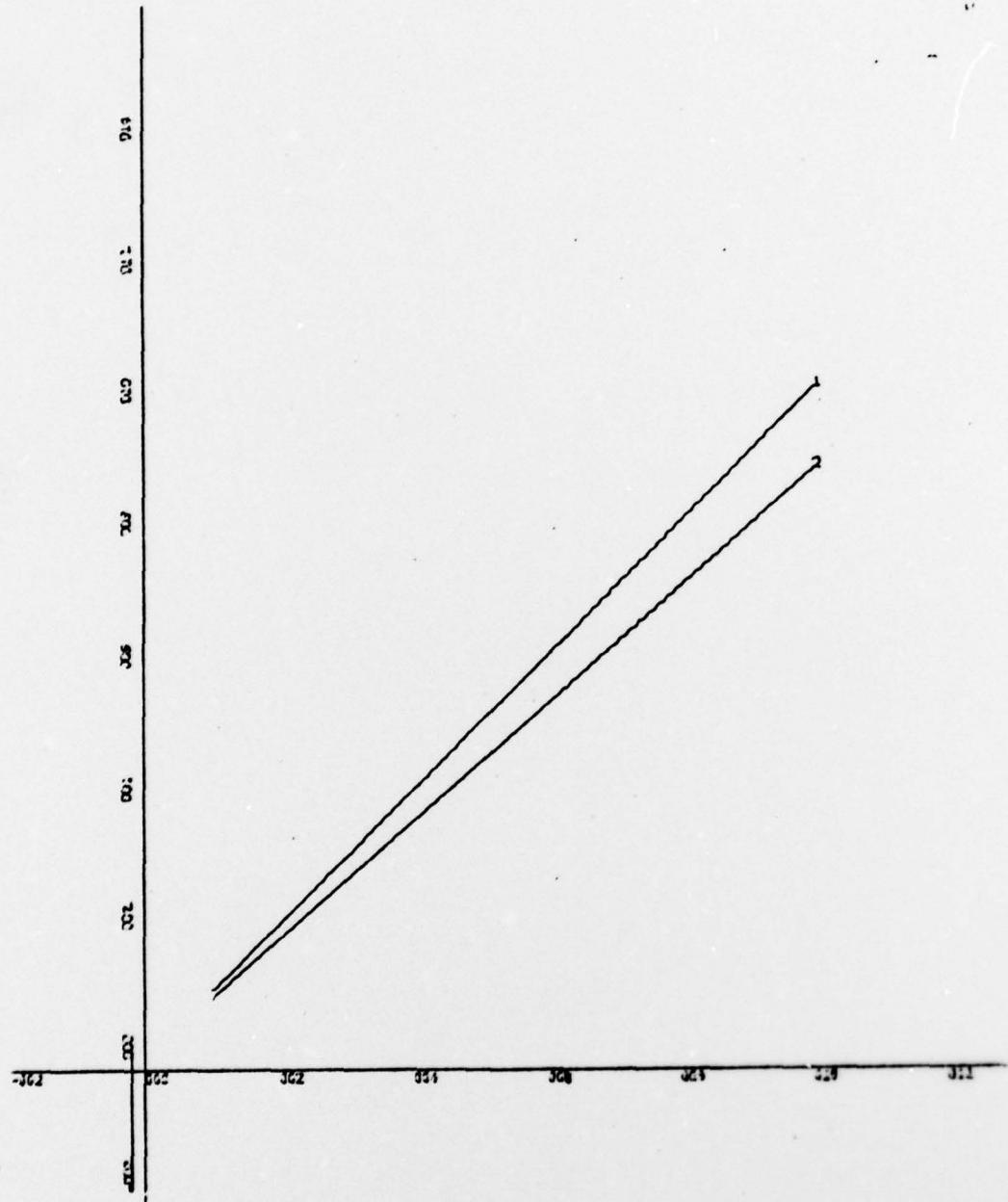
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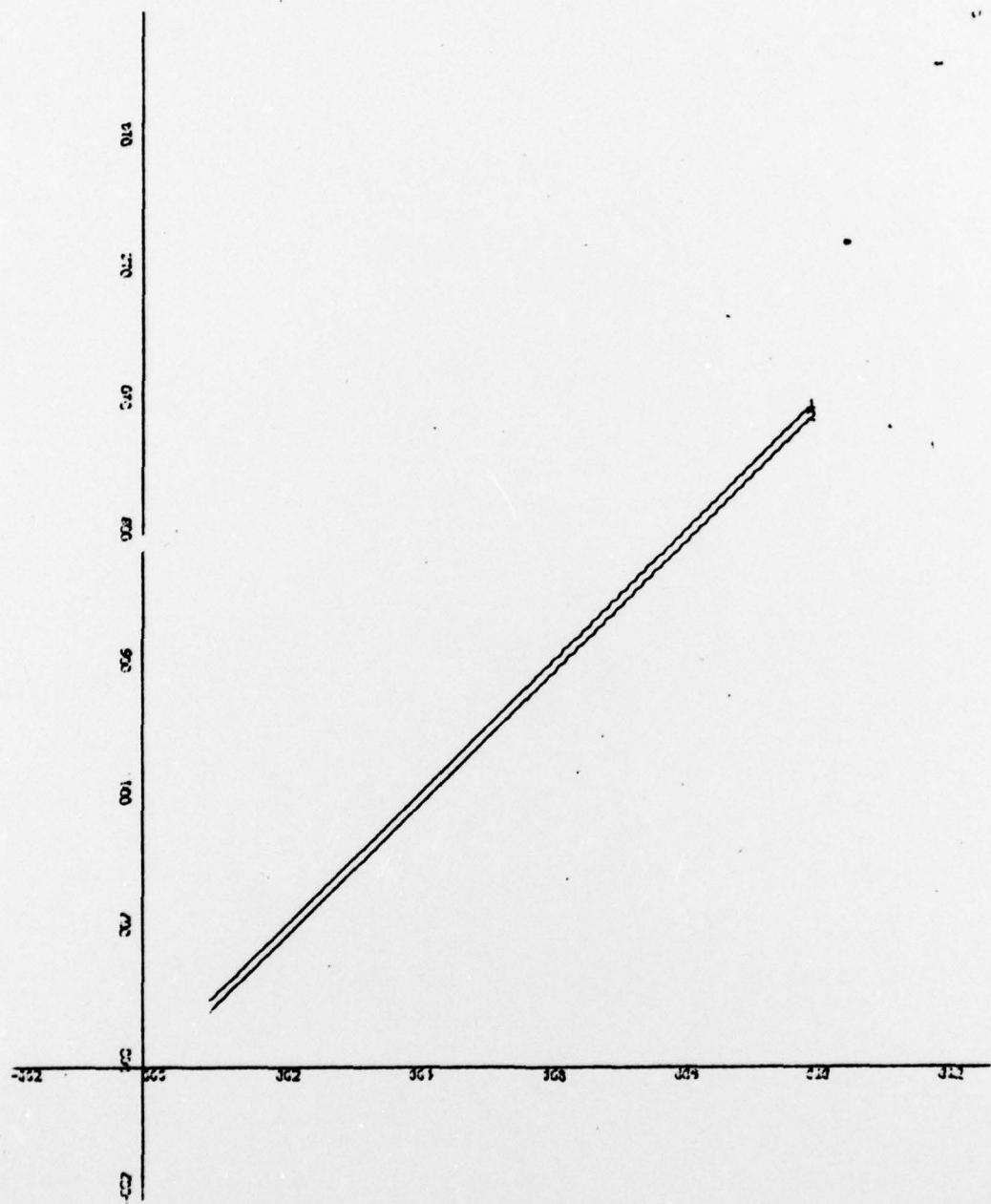
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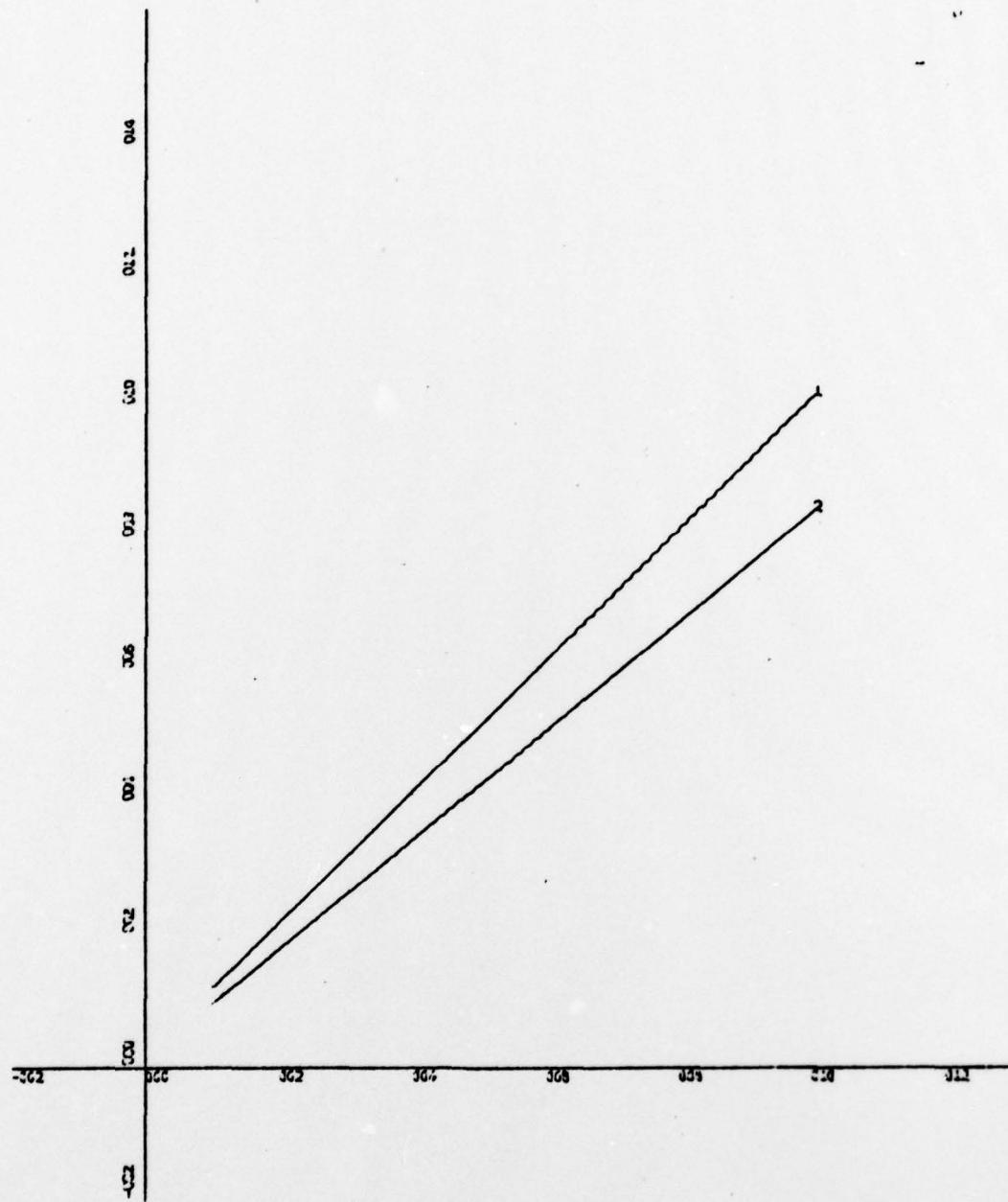
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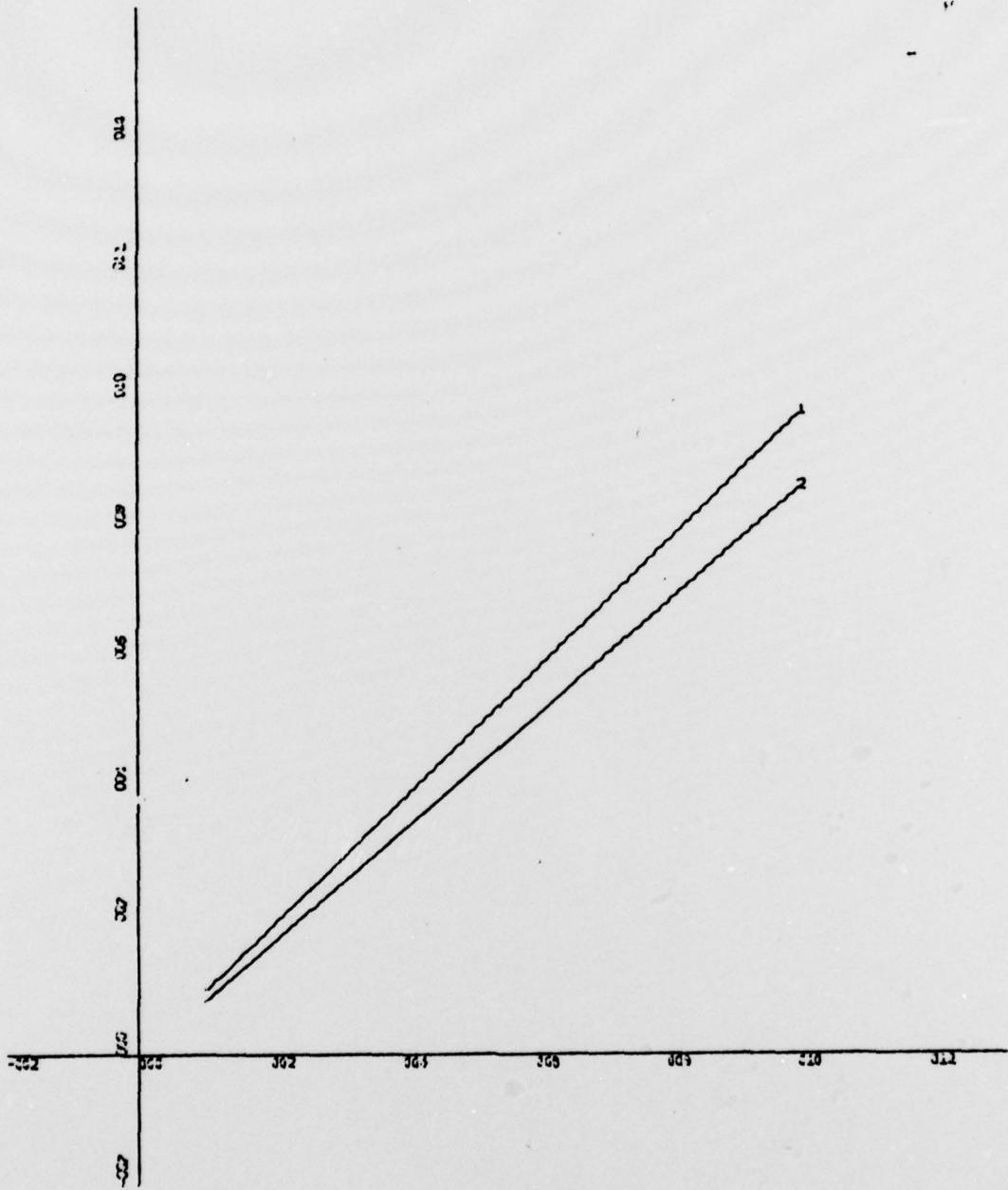
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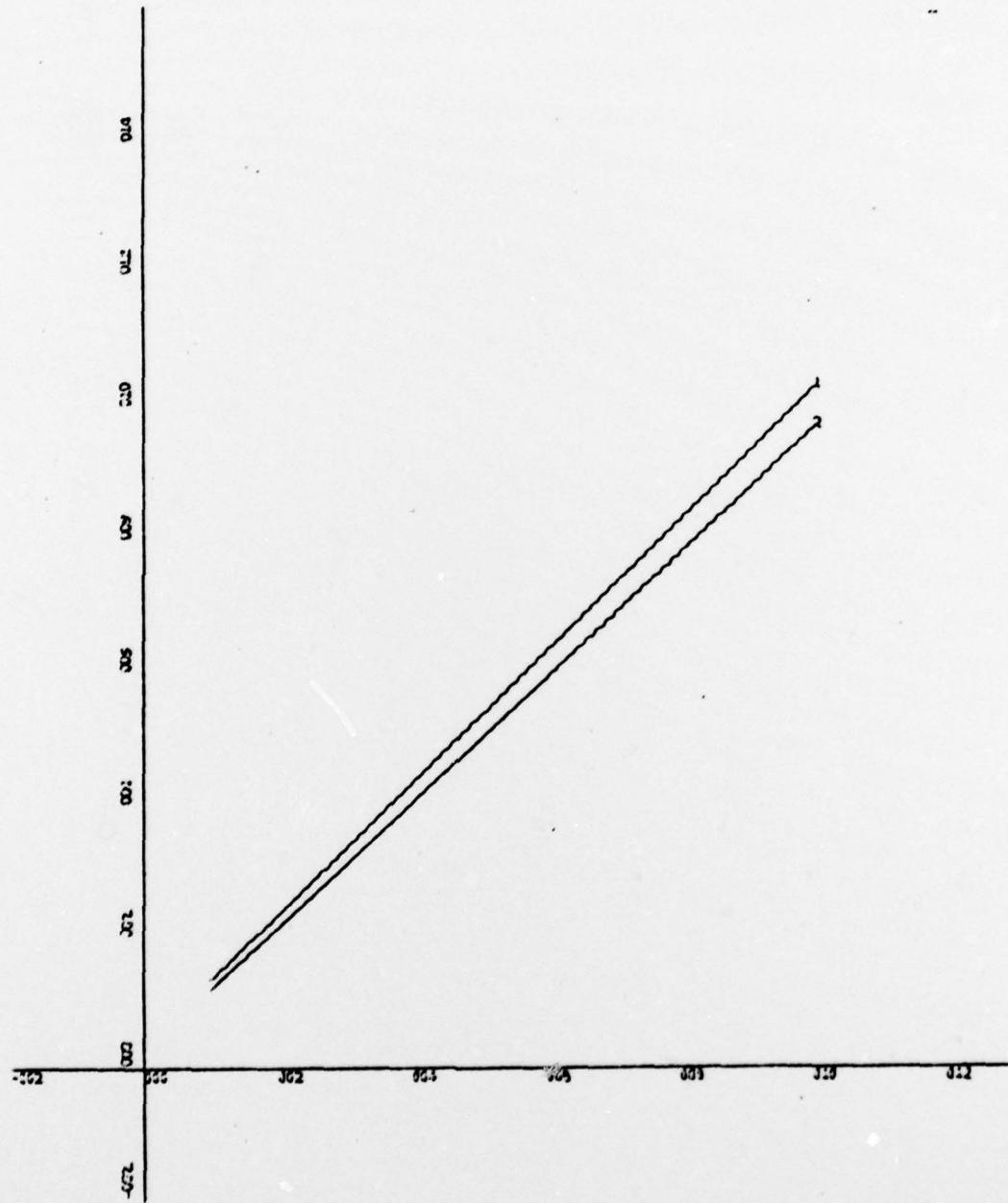
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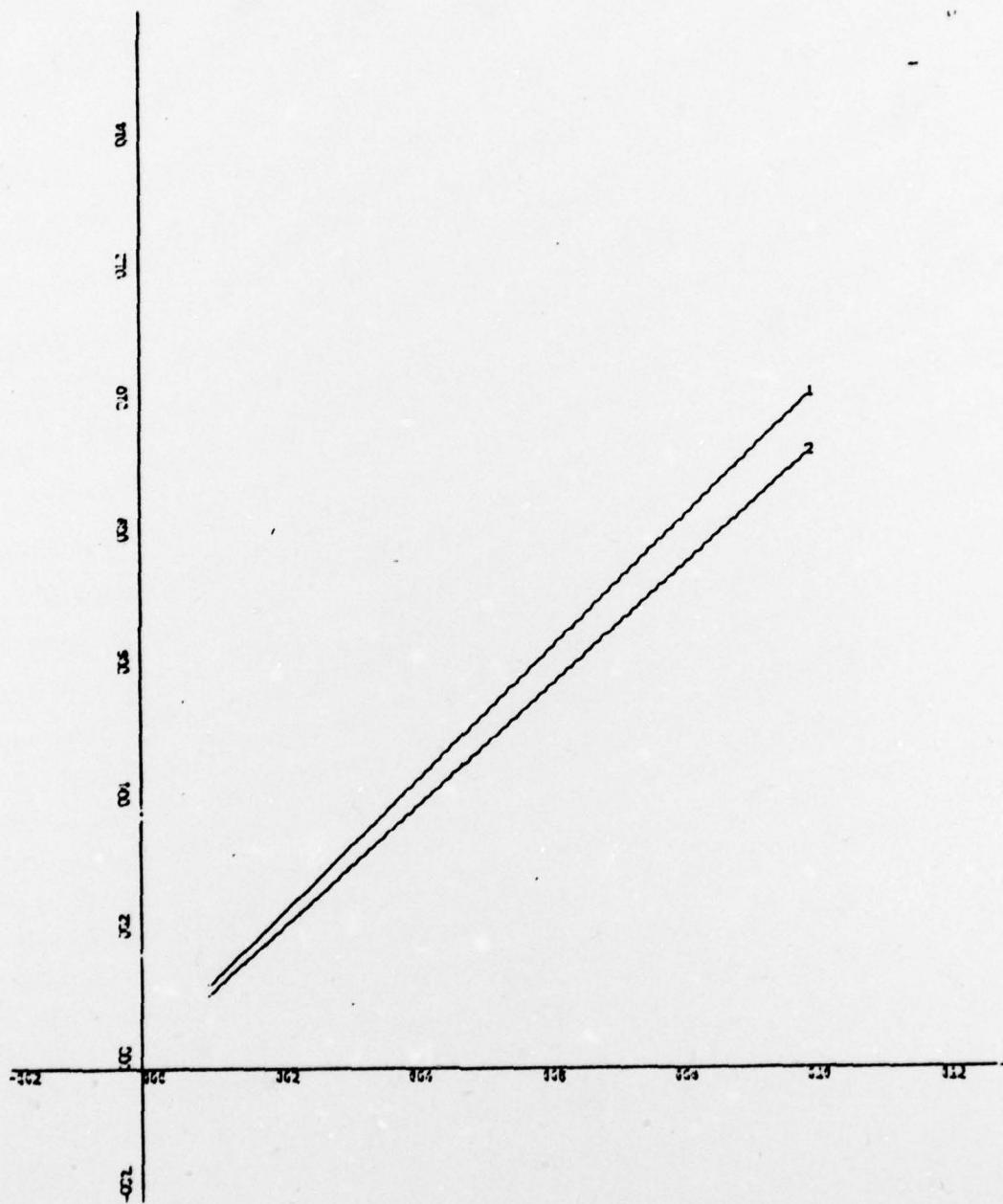
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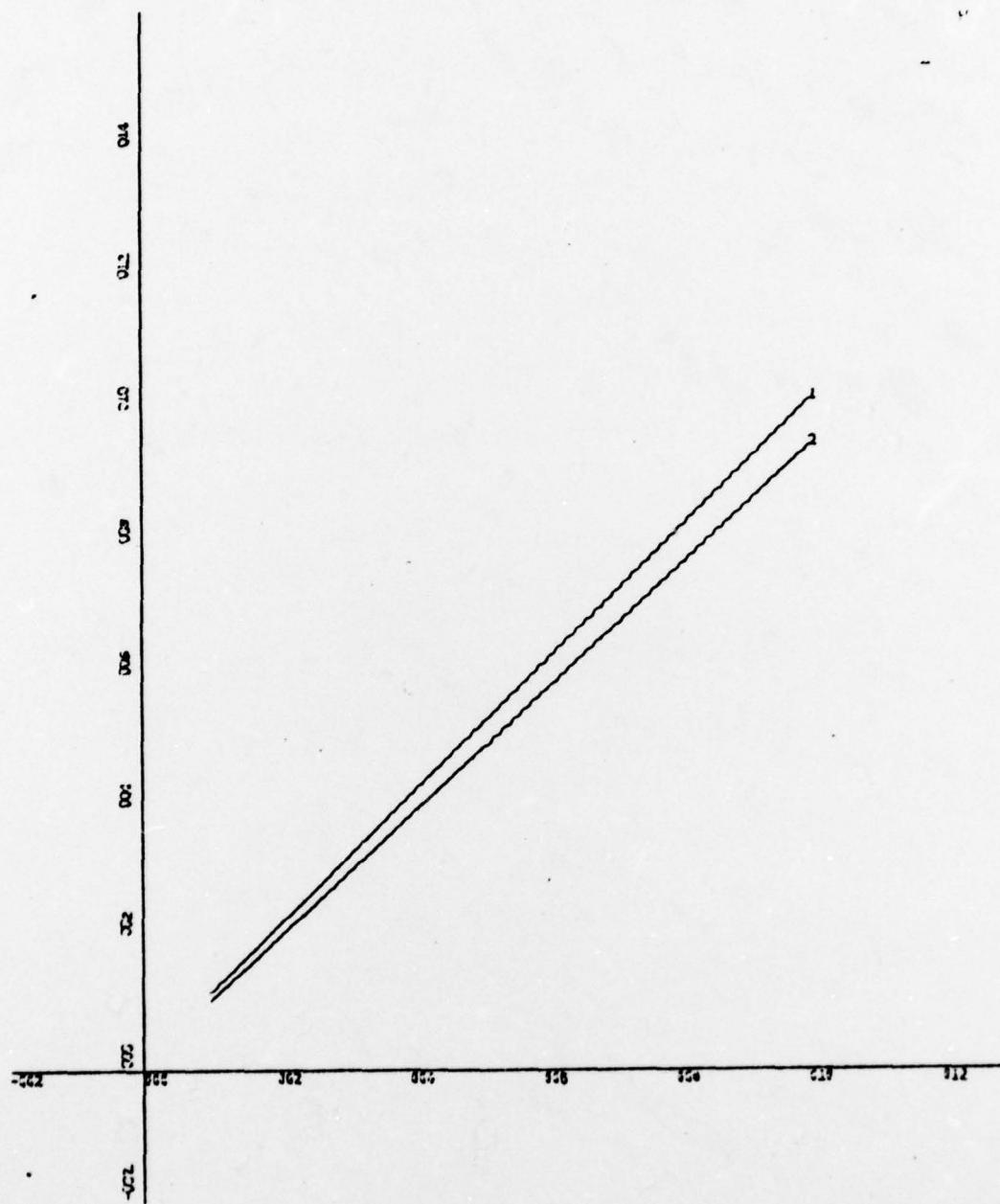
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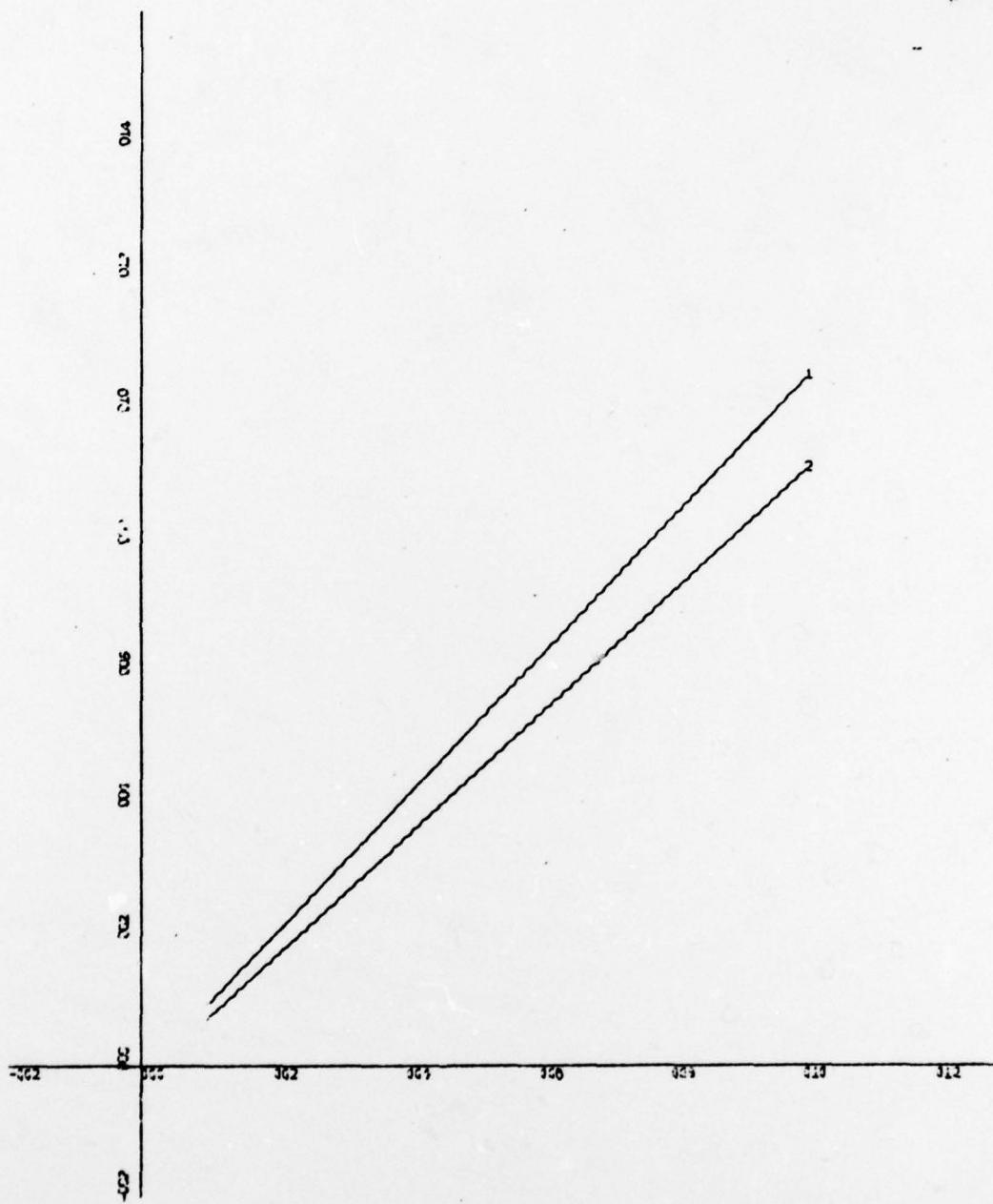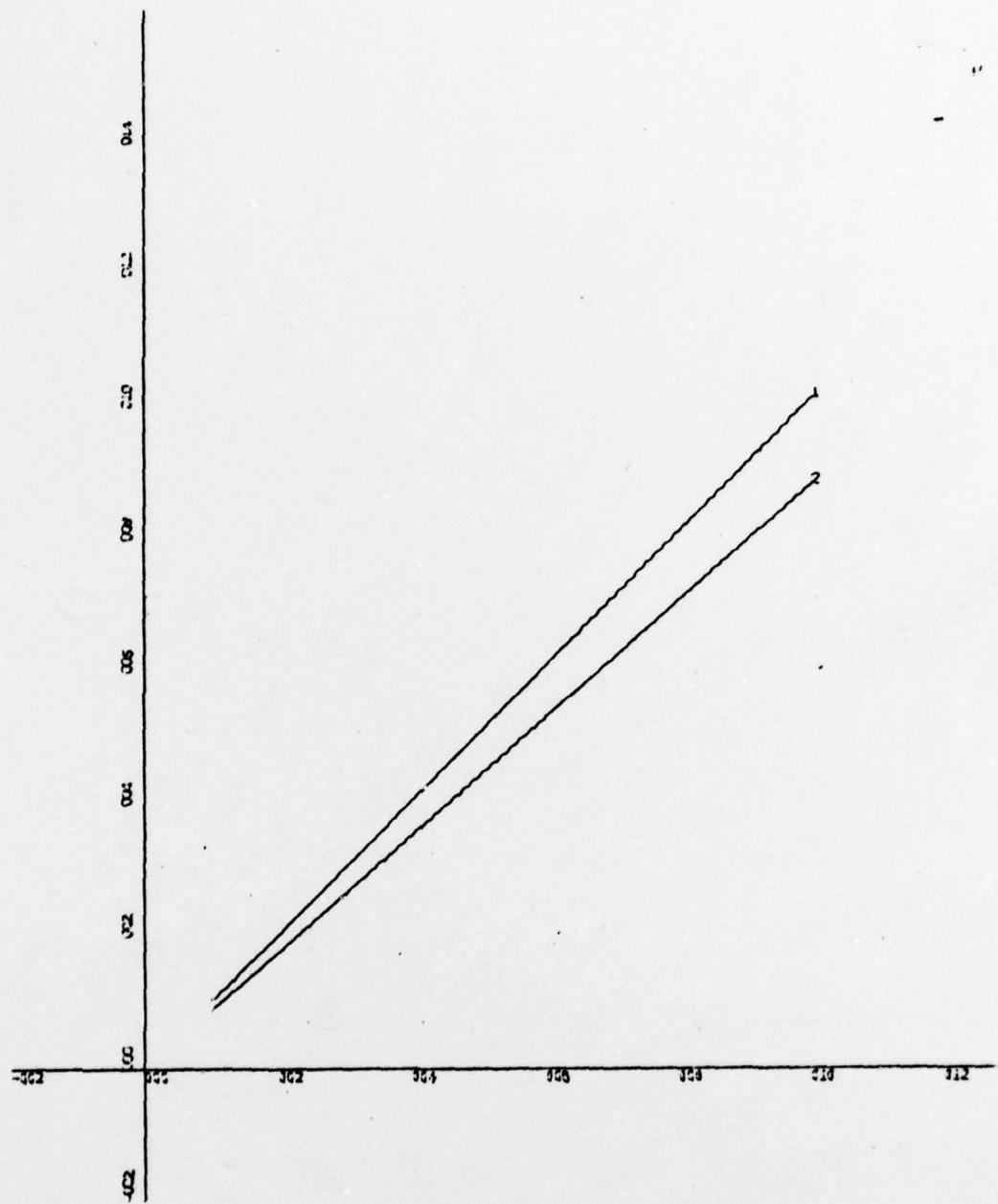
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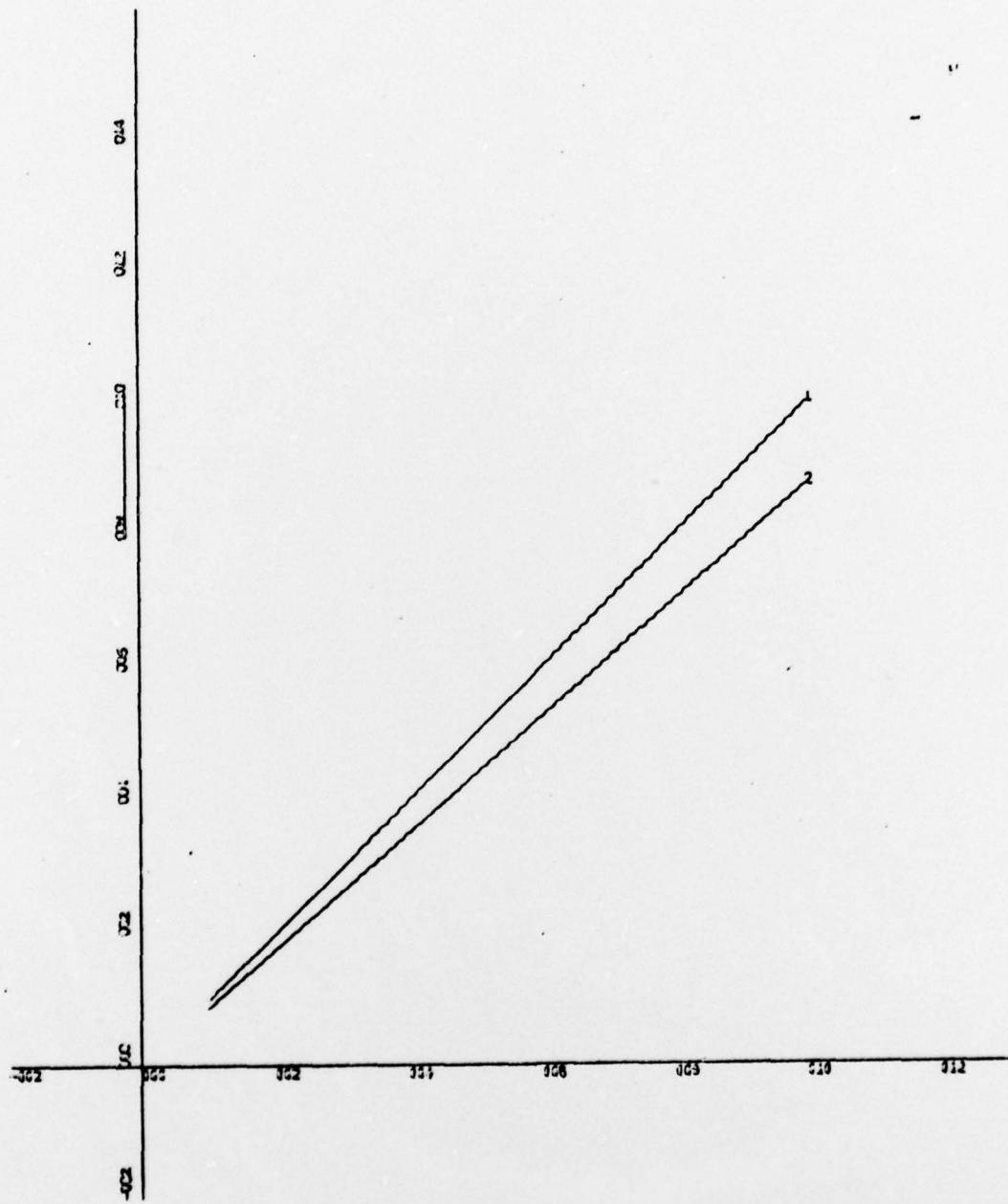
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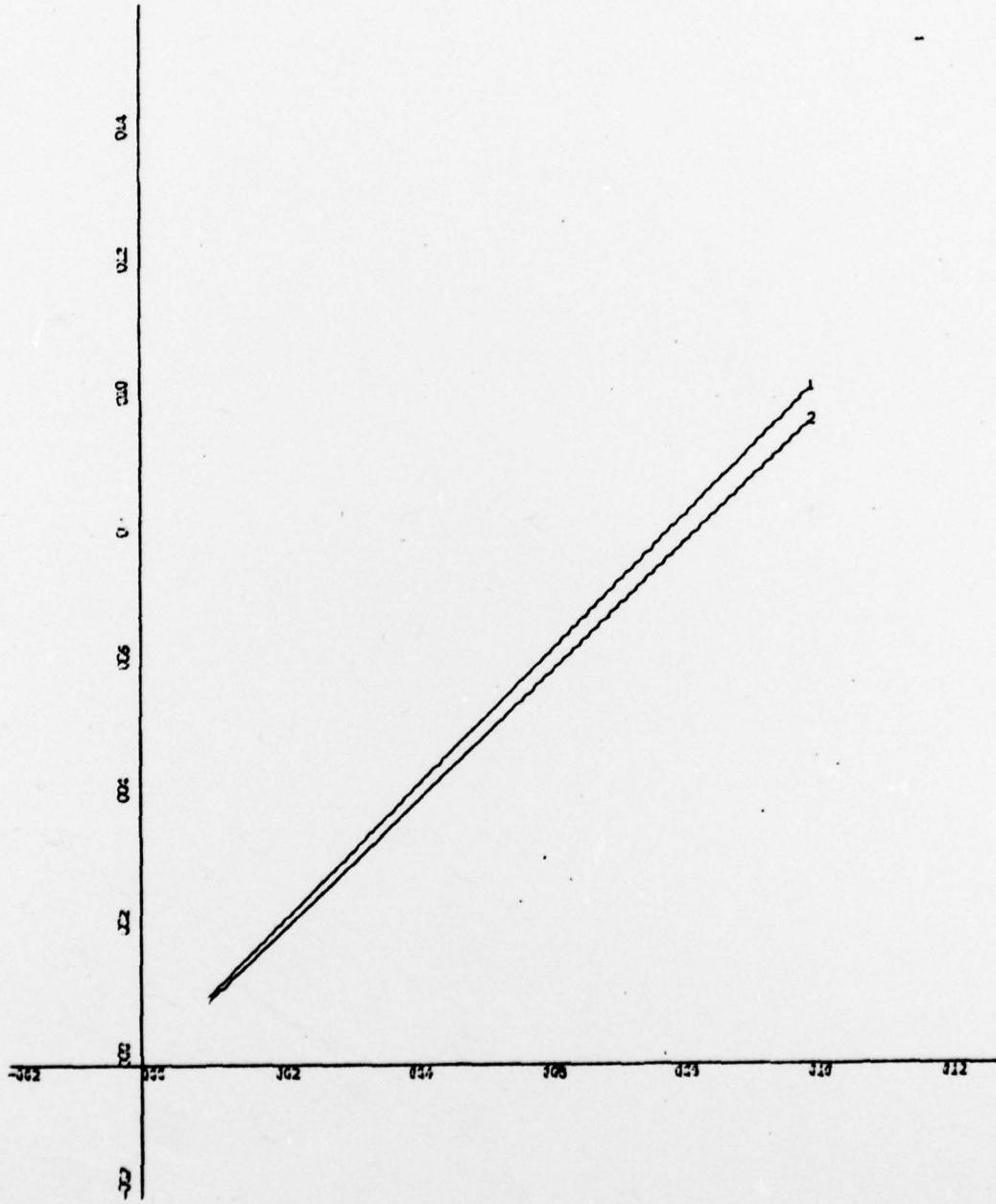
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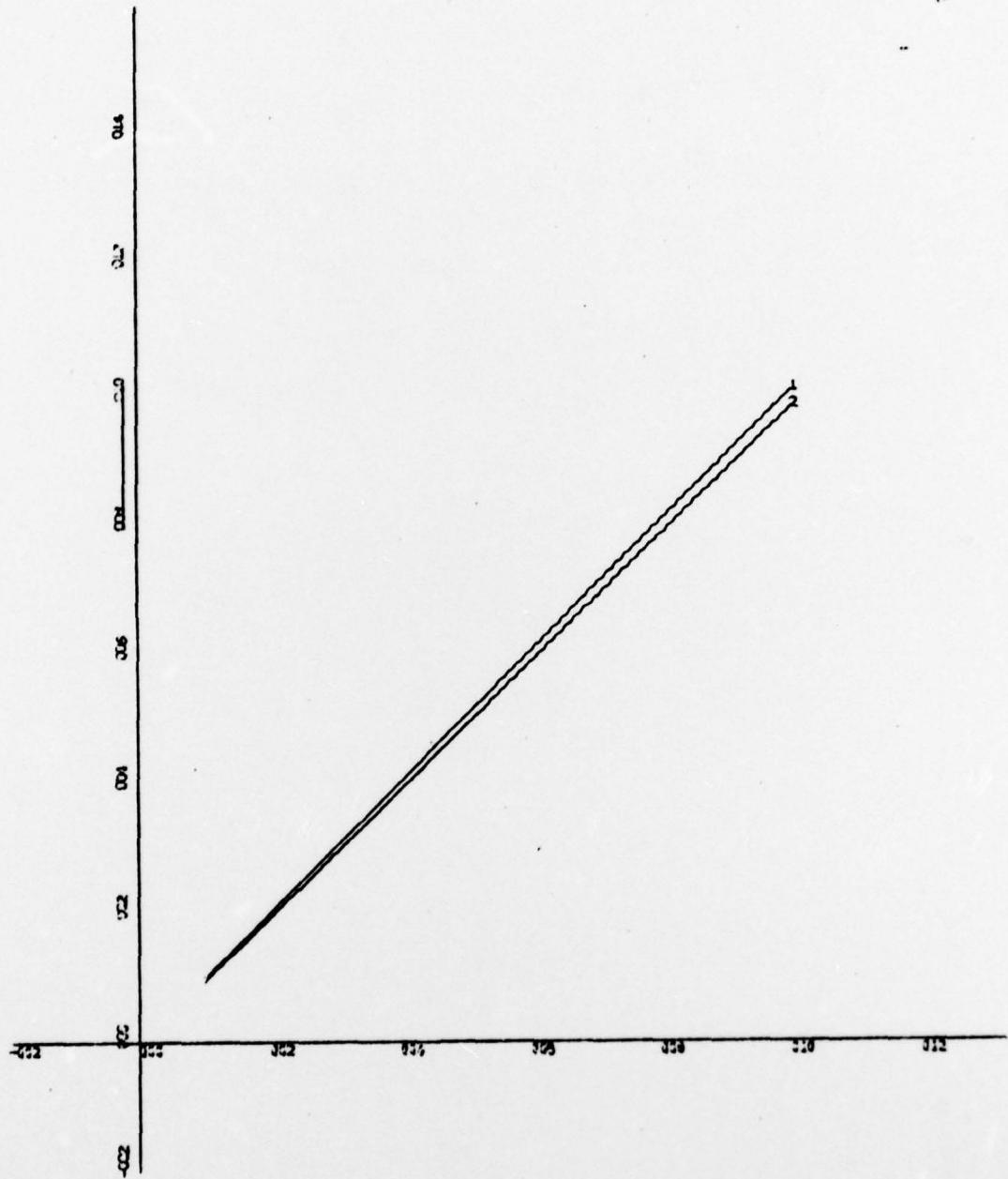
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